

Open charm B decays

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New results on B decays to charm-related modes from the Belle and CLEO experiments are presented.

1. Introduction

Studies of charm-related B decays provide information about the dynamics of B meson decays. Results of these fields can be used to check predictions of theoretical models. Recently new results appeared from the B factories at KEK and SLAC and from CLEO. This report covers the recent results on this subject from Belle [1] and CLEO [2].

The CLEO results are based on a 9.15 fb^{-1} data sample collected at the center-of-mass (CM) energy of the $\Upsilon(4S)$ resonance, while the Belle results are obtained using various data samples from 29.2 fb^{-1} to 78.7 fb^{-1} . Both groups identify B candidates by two kinematic variables: the energy difference, $\Delta E = (\sum_i E_i) - E_b$, and the beam constrained mass, $M_{bc} = \sqrt{E_b^2 - (\sum_i \vec{p}_i)^2}$, where $E_b = \sqrt{s}/2$ is the beam energy and \vec{p}_i and E_i are the momenta and energies of the decay products of the B meson in the CM frame.

2. $B \rightarrow D\pi$ Isospin Analysis (CLEO Collaboration)

Precise measurements of the $B \rightarrow D\pi$ branching fractions can be used to extract of the strong phase difference δ_I between the $I = 1/2$ and $I = 3/2$ isospin amplitudes in the $D\pi$ system. Observation of the color-suppressed $\bar{B}^0 \rightarrow D^0\pi^0$ decay [3,4] completed the measurements of the $D\pi$ final states. Recently CLEO collaboration improved the accuracy in the $B^- \rightarrow D^0\pi^-$ and $\bar{B}^0 \rightarrow D^+\pi^-$ branching fractions [5], these results are presented here.

D^0 mesons are reconstructed using three decay channels $D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$ and $K^-\pi^+\pi^0$. Charged D mesons are reconstructed

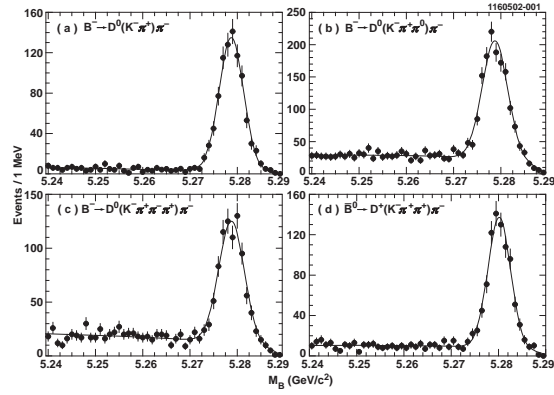


Figure 1. The M_{bc} distributions for the $B \rightarrow D\pi$ candidates.

via the mode $K^-\pi^+\pi^+$. In each case, D candidates are required to have an invariant mass within 3σ of the nominal D mass. The fitted M_{bc} distributions for each of the D decay modes are presented in Fig. 1. The following branching fractions have been obtained: $\mathcal{B}(B^- \rightarrow D^0\pi^-) = (4.97 \pm 0.12 \pm 0.29 \pm 0.22) \times 10^{-3}$ and $\mathcal{B}(\bar{B}^0 \rightarrow D^+\pi^-) = (2.68 \pm 0.12 \pm 0.24 \pm 0.12) \times 10^{-3}$. Here the first error is statistical, the second is systematic and the third one is a separate systematic error due to the experimental uncertainty of the production fractions of charged and neutral B mesons from $\Upsilon(4S)$ decays. Using the measurements of $\mathcal{B}(\bar{B}^0 \rightarrow D^0\pi^0)$ [3,4], $\cos \delta_I = 0.863^{+0.024+0.036+0.038}_{-0.023-0.035-0.030}$ has been obtained. The difference of δ_I from zero is 2.3σ indicating the presence of final state interactions in $B \rightarrow D\pi$ decays.

Table 1

The signal yields and branching fractions for the $\bar{B}^0 \rightarrow D_s^+ K^-$ and $B^0 \rightarrow D_s^+ \pi^-$ decay channels.

Mode	$M(D_s) - \Delta E$ yield	$M(D_s)$ yield	ΔE yield	\mathcal{B} (10^{-5})	Significance
$\bar{B}^0 \rightarrow D_s^+ K^-$	$16.4^{+4.6}_{-3.9}$	$15.0^{+4.5}_{-3.8}$	$17.5^{+4.8}_{-4.2}$	$4.6^{+1.2}_{-1.1} \pm 1.3$	6.4σ
$B^0 \rightarrow D_s^+ \pi^-$	$10.1^{+4.4}_{-3.7}$	$10.3^{+4.1}_{-3.4}$	$9.5^{+4.5}_{-3.8}$	$2.4^{+1.0}_{-0.8} \pm 0.7$	3.6σ

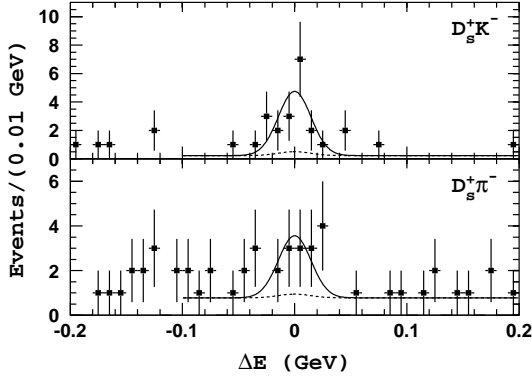


Figure 2. The ΔE spectra for the $\bar{B}^0 \rightarrow D_s^+ K^-$ (top) and $B^0 \rightarrow D_s^+ \pi^-$ (bottom) candidates.

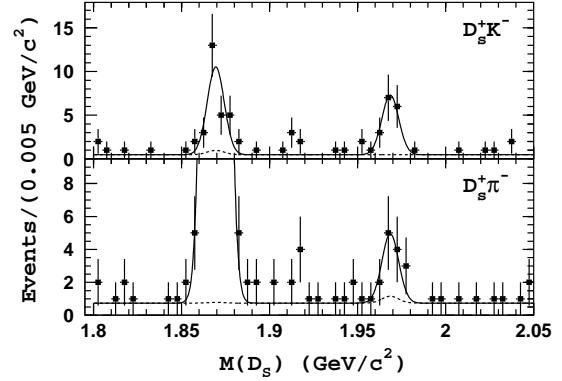


Figure 3. The $M(D_s)$ spectra for the $\bar{B}^0 \rightarrow D_s^+ K^-$ (top) and $B^0 \rightarrow D_s^+ \pi^-$ (bottom) candidates.

3. $B \rightarrow D_s \pi / K$ (Belle Collaboration)

The decay $B^0 \rightarrow D_s^+ \pi^-$ is expected to be dominated by a $b \rightarrow u$ transition, with no penguin contribution. Therefore, it can provide a way to determine the CKM matrix element, $|V_{ub}|$ [6]. The decay $\bar{B}^0 \rightarrow D_s^+ K^-$ can occur via W -exchange or final state rescattering and cannot be described by a spectator graph. The measurement of this decay mode can be used to estimate W -exchange or final state rescattering contributions in other B decays. Only upper limits have been reported for these decays by CLEO [7]. Recently, the BaBar collaboration presented evidence for the $B^0 \rightarrow D_s^+ \pi^-$ decay [8].

Here Belle results [9] on a search for these decays are presented. The D_s^+ candidates are reconstructed in the $D_s^+ \rightarrow \phi \pi^+$, $\bar{K}^{*0} K^+$ and $K_S^0 K^+$ decay channels. D_s^+ candidates are combined with a charged kaon or pion to form a B meson. To extract the signal, a binned maximum likelihood fit to the two-dimensional distribution of data in $M(D_s)$ and ΔE is performed.

The D_s^+ signal is described by a two-dimensional Gaussian, while the background function includes three components: combinatorial (flat in $M(D_s)$ and ΔE), $q\bar{q}$ events that peak in $M(D_s)$ and are flat in ΔE , and B decay events that peak in ΔE and are flat in $M(D_s)$. The levels of three background components are allowed to vary independently in the three reconstructed D_s^+ modes.

Figures 2 and 3 show the ΔE and $M(D_s)$ projections for events from the signal region, the fitted signal plus background combined shape by solid lines and background shape including the peaking background by dashed lines. In addition to the clear signals at the D_s^+ mass in Fig. 3, also seen are peaks at the D^+ mass, corresponding to the $\bar{B}^0 \rightarrow D^+ \pi^-$ and $\bar{B}^0 \rightarrow D^+ K^-$ decays. The fit results are given in Table 1. The results of one-dimensional fits to the $M(D_s)$ and ΔE distributions are also shown in Table 1 for comparison. A statistically significant signal (6.4σ) is observed for the $\bar{B}^0 \rightarrow D_s^+ K^-$ decay channel, while only evidence is reported for the $B^0 \rightarrow D_s^+ \pi^-$ decay.

Table 2

The branching fractions and resonance parameters for the $D^{(*)+}\pi^-\pi^-$ final states.

Mode	$\mathcal{B}(B^- \rightarrow D_X \pi^-) \mathcal{B}(D_X \rightarrow D^{(*)+} \pi^-)$	$M(D_X)$, MeV/ c^2	$\Gamma(D_X)$, MeV/ c^2
$B^- \rightarrow D_2^{*0} \pi^- \rightarrow D^+ \pi^- \pi^-$	$(3.5 \pm 0.3 \pm 0.5) \times 10^{-4}$	$2460.7 \pm 2.1 \pm 3.1$	$46.4 \pm 4.4 \pm 3.1$
$B^- \rightarrow D_0^{*0} \pi^- \rightarrow D^+ \pi^- \pi^-$	$(5.5 \pm 0.5 \pm 0.8) \times 10^{-4}$	$2290 \pm 22 \pm 20$	$300 \pm 30 \pm 30$
$B^- \rightarrow D_v^{*0} \pi^- \rightarrow D^+ \pi^- \pi^-$	$(1.4 \pm 0.3 \pm 0.2) \times 10^{-4}$	[10]	[10]
$B^- \rightarrow D_1 \pi^- \rightarrow D^{*+} \pi^- \pi^-$	$(6.2 \pm 0.5 \pm 1.1) \times 10^{-4}$	$2423.9 \pm 1.7 \pm 0.2$	$26.7 \pm 3.1 \pm 2.2$
$B^- \rightarrow D_2^{*0} \pi^- \rightarrow D^{*+} \pi^- \pi^-$	$(2.0 \pm 0.3 \pm 0.5) \times 10^{-4}$	[13]	[13]
$B^- \rightarrow D_1^{*0} \pi^- \rightarrow D^{*+} \pi^- \pi^-$	$(4.1 \pm 0.5 \pm 0.8) \times 10^{-4}$	$2400 \pm 30 \pm 20$	$380 \pm 100 \pm 100$

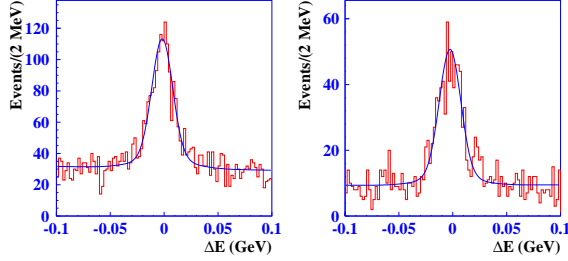


Figure 4. The ΔE distributions for the $B^- \rightarrow D^+ \pi^- \pi^-$ (left) and $B^- \rightarrow D^{*+} \pi^- \pi^-$ (right) candidates.

4. $B^- \rightarrow D^{(*)+} \pi^- \pi^-$ (Belle Collaboration)

A study of charmed meson production in B decays provides an opportunity to test predictions of Heavy Quark Effective Theory (HQET) and QCD sum rules. B decays to $D^{(*)} \pi$ final states are the dominant hadronic B decay modes and are measured quite well [10]. The large data sample accumulated in the Belle experiment allows to study production of D meson excited states. D^{**} s are P-wave excitations of quark-antiquark systems that contain one charmed and one light (u, d) quark. The $B \rightarrow D^{**} \pi$ decays have been studied by Belle [11] using the $D^+ \pi^- \pi^-$ and the $D^{*+} \pi^- \pi^-$ final states.

Figure 4 shows the ΔE distributions for the $B^- \rightarrow D^+ \pi^- \pi^-$ and $B^- \rightarrow D^{*+} \pi^- \pi^-$ candidates. The following branching fractions are measured: $\mathcal{B}(B^- \rightarrow D^+ \pi^- \pi^-) = (1.07 \pm 0.05 \pm 0.16) \times 10^{-3}$ and $\mathcal{B}(B^- \rightarrow D^{*+} \pi^- \pi^-) = (1.24 \pm 0.07 \pm 0.22) \times 10^{-3}$, without any assumption about the intermediate final states.

To study the dynamics of $B \rightarrow D^{(*)} \pi \pi$ decays,

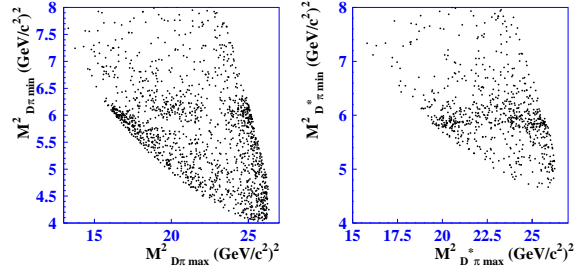


Figure 5. The Dalitz plot distributions for $B^- \rightarrow D^+ \pi^- \pi^-$ (left) and $B^- \rightarrow D^{*+} \pi^- \pi^-$ (right) candidates.

an analysis of the Dalitz plots shown in Fig. 5 is performed. The fit to the $D^+ \pi^- \pi^-$ Dalitz plot includes three final states: $D_2^{*0} \pi^-$, $D_0^{*0} \pi^-$ and the contribution of the process with virtual $D^{*0} \pi$ production ($D_v^{*0} \pi^-$). The results are presented in Table 2.

Two additional degrees of freedom should be taken into account in the $D^{*+} \pi^- \pi^-$ final state: the angle (α) between the pion from the D^{**} decay and the pion from the D^* decay in the D^* rest frame and the azimuthal angle (γ) of this particle relative to the plane of the $B^- \rightarrow D^{*+} \pi^- \pi^-$ decay. The fit to the $D^{*+} \pi^- \pi^-$ distribution includes three final states: $D_1 \pi^-$, $D_2^{*0} \pi^-$ and $D_1^{*0} \pi^-$. The results are presented in Table 2.

Using these measurements the ratio of D_2^{*0} branching fractions $h = \mathcal{B}(D_2^{*0} \rightarrow D^+ \pi^-) / \mathcal{B}(D_2^{*0} \rightarrow D^{*+} \pi^-) = 1.77 \pm 0.49$, consistent with the world average $h = 2.3 \pm 0.6$ [10], is obtained. The measured ratio $R = \mathcal{B}(B^- \rightarrow D_2^{*0} \pi^-) / \mathcal{B}(B^- \rightarrow D_1^{*0} \pi^-) = 0.89 \pm 0.14$ is lower than the CLEO measurement 1.8 ± 0.8 [12] (al-

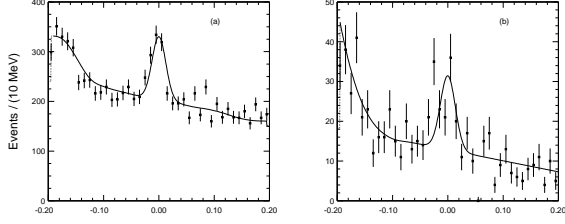


Figure 6. The ΔE distributions for (a) $\bar{B}^0 \rightarrow D^0\pi^+\pi^-$ and (b) $\bar{B}^{*0} \rightarrow D^0\pi^+\pi^-$ candidates.

though the results are consistent within errors) but is still a factor of 3 larger than the factorization prediction [14]. Belle measurements show that the narrow resonances compose $(33 \pm 4)\%$ of the $D\pi\pi$ decays and $(66 \pm 7)\%$ of the $D^*\pi\pi$ decays. This result is inconsistent with the QCD sum rule prediction and may indicate a large contribution from a color suppressed amplitude.

5. $\bar{B}^0 \rightarrow D^{(*)0}\pi^+\pi^-$ (Belle Collaboration)

Exclusive hadronic decay rates provide important tests of models for B meson decays. The $\bar{B}^0 \rightarrow D^{(*)0}\pi^+\pi^-$ decays provide a precision testing ground for factorization [15] and the possibility to search for resonant substructure in the final state. At present, only an upper limit $\mathcal{B}(\bar{B}^0 \rightarrow D^0\pi^+\pi^-) < 1.6 \times 10^{-3}$ [16] exists.

Here the Belle results [17] on a study of these decays are presented. D^0 candidates are reconstructed in the $K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$ and $K^-\pi^+\pi^0$ final states. Figure 6 shows the ΔE distributions for the $\bar{B}^0 \rightarrow D^{(*)0}\pi^+\pi^-$ candidates. The following branching fractions are measured: $\mathcal{B}(\bar{B}^0 \rightarrow D^0\pi^+\pi^-) = (7.5 \pm 0.7 \pm 1.5) \times 10^{-4}$ and $\mathcal{B}(\bar{B}^0 \rightarrow D^{*0}\pi^+\pi^-) = (6.2 \pm 1.2 \pm 1.7) \times 10^{-4}$. Figure 7 shows the $\pi^+\pi^-$ invariant mass spectra for the selected events. These distributions are fitted by a sum of the ρ^0, σ and $f_0(1370)$ resonances. The amplitudes and phases are free parameters in the fit. The branching fraction of $\mathcal{B}(\bar{B}^0 \rightarrow D^0\rho^0) = (3.0 \pm 1.2 \pm 0.4) \times 10^{-4}$ and the 90% CL upper limit $\mathcal{B}(\bar{B}^0 \rightarrow D^{*0}\rho^0) < 5.1 \times 10^{-4}$ are obtained.

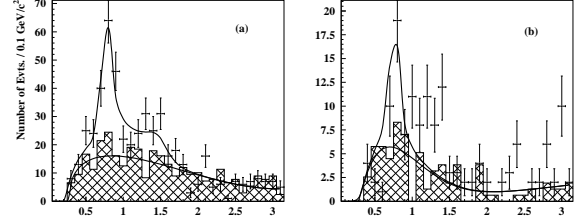


Figure 7. The $\pi^+\pi^-$ invariant mass spectra for the (a) $\bar{B}^0 \rightarrow D^0\pi^+\pi^-$ and (b) $\bar{B}^{*0} \rightarrow D^0\pi^+\pi^-$ candidates.

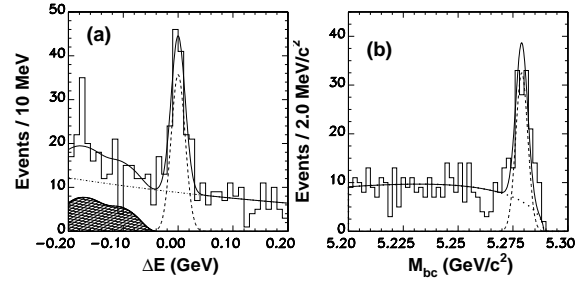


Figure 8. The (a) ΔE , (b) M_{bc} distributions for the $B^- \rightarrow D^0K^{*-}$ candidates.

6. $B^- \rightarrow D^0K^{*-}$ (Belle Collaboration)

The decay $B^- \rightarrow D^0K^{*-}$ can be used for ϕ_3 determination [18]. This mode has been previously observed by the CLEO Collaboration [19].

D^0 mesons are reconstructed in the decay channels $D^0 \rightarrow K^-\pi^+$, $K^-\pi^+\pi^-\pi^+$ and $K^-\pi^+\pi^0$ using a 2σ mass window from the nominal D^0 mass. The K^{*-} candidates are combined from the $K_S^0\pi^-$ pairs.

The ΔE and M_{bc} distributions are presented in Fig. 8(a) and (b) respectively. A signal of 114.4 ± 13.5 events with 10.9σ statistical significance is observed. The fit results are presented in Table 3. The measured branching fraction $\mathcal{B}(B^- \rightarrow D^0K^{*-}) = (5.4 \pm 0.6 \pm 0.8) \times 10^{-4}$ agrees well with the world average [10]. Figure 9 shows the K^{*-} helicity and invariant mass distributions obtained by fitting the M_{bc} spectra in each bin.

Table 3

The signal yields and branching fractions for the $B^- \rightarrow D^0 K^{*-}$ decay channel.

Decay mode	ΔE yield	M_{bc} yield	\mathcal{B} (10^{-4})
$D^0 \rightarrow K^- \pi^+$	52.5 ± 8.1	51.6 ± 8.5	$6.1 \pm 0.9 \pm 0.8$
$D^0 \rightarrow K^- \pi^+ \pi^0$	36.1 ± 6.8	32.9 ± 6.4	$5.1 \pm 0.9 \pm 0.7$
$D^0 \rightarrow K^- \pi^+ \pi^+ \pi^-$	31.0 ± 7.0	29.4 ± 6.8	$4.6 \pm 1.1 \pm 0.8$
Weighted mean			$5.4 \pm 0.6 \pm 0.8$

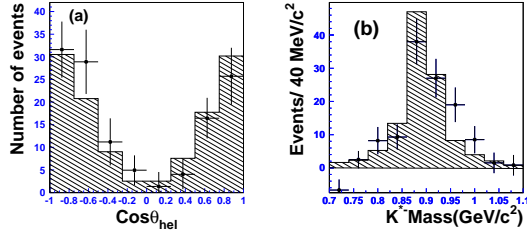


Figure 9. The (a) K^{*-} helicity and (b) K^{*-} invariant mass distributions for the $B^- \rightarrow D^0 K^{*-}$ signal region.

7. Conclusion

A nonzero strong phase δ_I is obtained using the CLEO and Belle measurements of the branching fractions $\mathcal{B}(B \rightarrow D\pi)$. The 2.3σ difference from zero indicates the presence of final state interactions in $B \rightarrow D\pi$ decays. The observation of the $\bar{B}^0 \rightarrow D_s^+ K^-$ decay by Belle emphasizes the importance of W exchange or final state rescattering. In $B^- \rightarrow D^{(*)+} \pi^- \pi^-$ decays all four P-wave D^{**} have been observed and their parameters have been measured by Belle. For the broad D_0^{*0} and D_1^{*0} states this is the first measurement.

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